SUBJECT: Status Report on the NASA Grant NGR-39-007-011

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In most thin plate and shell structures usually the main component of loading is that which gives rise to meridional stresses. Hence, the studies reported in literature and dealing with the fatigue phenomenon in such structures are somewhat justifiably confined to extensional loading of flat plates. On the other hand in some sheet-stringer structures the non-meridional components of the loading, notably the bending and twisting, may also be present and significant. Also the theoretical stress calculations indicate that in shells, depending on the thickness to radius of curvature ratio, the stress state around imperfections such as holes and cracks may be considerably different than the stresses in flat plates with similar imperfections. Thus the main question to which the present research program addresses itself is the following: Knowing the fatigue crack initiation and growth characteristics in thin plates under plane extensional type of loading, can the same characteristics be predicted for structures composed of thin sheets with more general geometry and under more general types of loading, and can a rational theoretical basis of comparison be developed to achieve this end? The following is the present status of the program:

1. Theoretical work

The part of the theoretical work dealing with the investigation of the model which was proposed to be used as a basis of comparison for crack growth characteristics in various plate and shell structures under various types of loading was given in the paper "A Comparative Study of Crack Propagation in Plates Under Extension and Bending", by F. Erdogan and R. Roberts, which was presented at the International Conference on Fracture in Sendai, Japan, Sept. 12-17, 1965 and submitted to NASA as an interim report. According to this model the most important single field quantity in the

quantitative analysis of the fatigue crack growth is the size of the plastic zone in the plane of crack propagation. The plastic zone size in turn can be estimated, within a reasonable degree of accuracy, from the elastic stress analysis. Thus the main part of the theoretical work has been devoted to the analysis of stresses around the imperfections in plates and shells. The solution for plates under cylindrical bending containing cracks emanating from circular holes is in its completion stage. This solution is needed for the quantitative studies of crack growth starting from holes and cutouts in plates. The problem of cracks in cylindrical shells under internal pressure and bending is in its initial stages.

In sheet structures with more complicated geometry, such as edge cracks, finite width and cracks emanating from holes of various shapes, the elastic analysis becomes intractable. In such cases one may use the longitudinal shear analogy to investigate the stress singularities and estimate the plastic zone size. For this purpose a new method has been developed and plastic zone sizes for a number of complicated crack geometries (involving homogeneous as well as bonded nonhomogeneous materials) have been calculated.

2. Experimental work:

The experimental work which is being carried on in this project may be divided into two different categories. The first is the straightforward testing for the purpose of verifying and improving the continuum-based theoretical models for the fatigue crack initiation (at the points of stress concentrations) and propagation in plates and shells. The second is the closer examination of the deformations and stresses in the neighborhood of a crack tip under cyclic load in order to verify the techniques used to evaluate certain field parameters (such as the plastic zone size) and study their dependence on the cyclic nature of the load.

The crack growth studies in plates under bending are expected to be completed by December 1, 1965, covering the practical ranges of load levels and plate thicknesses. The remaining work in this

area is the crack initiation studies and long-duration environmental testing by using various types of corrosive agents.

The modification of plate bending machine in order to adopt it to the bending of cylindrical shells has been designed and its construction should be completed by the time the plate tests are over.

In the machine which was designed to test flat plates with cracks subjected to extension and cyclic transverse shear loads, after the preliminary testing of a few plates, some changes have been made in order to improve the symmetry in loading conditions. The machine will soon be ready for testing with static extensional load. Further modification of the testing machine to cycle also the extensional component of the load is in design stage.

For the experimental work in cylindrical shells subjected to fluctuating internal pressure the complete system - the components purchased through the NASA Grant as well as those constructed at Lehigh - is now in operation. The sealing mechanism of the crack seems to function very satisfactorily and the crack growth is smooth. Presently we are testing 8" in diameter and 0.05 in. thick 2024-T3 aluminum shells. The program includes the testing of 7075-T6 aluminum as well as steel shells.

For the studies of deformations and stresses at the crack tip, the usual etching technique does not seem to give the desired quantitative information. The sensitivity of the Moire equipment which we have does not seem to be sufficiently high to be a basis of quantitative analysis. The quantitative experiments in this area will be performed with the small field Moire instrument which is about to be acquired by the University. The instrument works on the same principle as the ordinary Moire fringes, however it has a square array of dots instead of fringes and one may have as many as 1500 dots per inch on a given specimen. This means that in addition to its higher sensitivity the instrument is capable of measuring the total displacement field rather than one displacement component at a time as measured by the line-patterned Moire technique.